Analysis of more complex arrhythmias using the tangential components of the cardiac magnetic field

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1 Introduction

Patients with left ventricular dysfunction are at high risk for sudden death due to ventricular tachyarrhythmias. It is one of the most important issue how to detect high-risk patients and prevent sudden death. An invasive procedure, electro-physiologic study (EPS), is a “gold standard” in the diagnosis of arrhythmia. Although EPS-guided therapy had been expected to be better than empiric therapy [1], recent study reported that implantable cardioverter-defibrillators reduced the risk of sudden death, but EPS-guided anti-arrhythmic therapy did not [2]. Another reported that EPS suggested negative predictive value of sudden death [3]. It is contradictious whether repetitive EPS could reduce sudden death.

The aim of our studies is to improve noninvase magnetocardiograms (MCGs) so that they could replace diagnostic EPS as the gold standard. If radiofrequency catheter ablation (CA) is indicated, an invasive mapping is necessary. If CA is not indicated, a noninvasive diagnostic procedure would be better. We thus developed a magneto-anatomical mapping system and a beat-to-beat analysis by using the tangential components of the cardiac magnetic field. This paper is an outline of our studies.

2 Atrial arrhythmias [4]

Atrial flutter (AF) cannot be analyzed by using a single-dipole model, because it is a macro-reentrant tachycardia with a long activation time and a short excitable gap [5] [6]. In conventional MCG systems, the location of the magnetic source is usually calculated from the normal components of the cardiac magnetic field. The properties of a magnetic source calculated from the tangential components are corresponded more precisely with actual electro-physiological phenomena than those calculated from the normal components [7] [8] [9]. The aim of the present study was to analyze multidipole phenomena by using the tangential components.

2.1 Methods

Patients with common AF (due to macro-reentry) and atrial tachycardia (AT) (due to automaticity or micro-reentry) were evaluated by using a 64-channel MCG system with a 17.5*17.5 cm measuring area (Hitachi Ltd., Japan). The mechanisms and foci of their arrhythmias were also diagnosed through EPS. We measured the normal components of the cardiac magnetic field and analyzed both the normal and tangential components in a single beat. We analyzed isomagnetic field maps of the tangential components and produced an MCG animation with 1-ms intervals. AF was compared with AT through the animation.

2.2 Results

In MCG animation, peaks moved along a large circuit in AF but did not in AT. In AT, atrial activation showed unipolar pattern in the initiation and moved one-way pathway during the activation sequence (Figure 1).

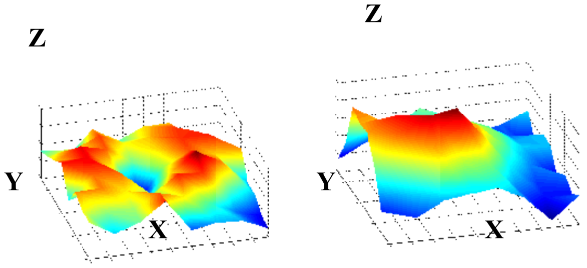


Figure 1: *Isomagnetic field maps during atrial flutter and atrial tachycardia*
During atrial flutter (left), atrial activation (the circular red pattern) showed a large circuit at the anterior chest. During atrial tachycardia (right), atrial activation (red area) showed unipolar pattern.
*X-Y line: a 64-channel measuring area of 17.5 * 17.5 cm, Z line: the cardiac magnetic strength of the tangential components.*

2.3 Conclusion

The multidipole arrhythmia "AF" was analyzed by using the tangential components of the cardiac magnetic field. MCGs animation clearly showed the mechanisms and foci of atrial arrhythmias noninvasively.

3 Magneto-anatomical mappings [10]

We superimposed MCGs on magnetic resonance images (MRs) to display both electrophysiological and anatomical information, and named the results magneto-anatomical mappings. In the analysis of multidipole phenomena (Section 2), MCGs were superimposed on two-dimensional (2D) MRs. In the early phase of pre-excitation and automaticity, the activation pattern is considered to be a single-dipole model. To gain precise anatomical information about a single-dipole phenomenon, we made a three-dimensional (3D) magneto-anatomical mapping system.

3.1 Methods

Patients with Wolff-Parkinson-White (WPW) syndrome who had been successfully treated by CA were studied using MCGs (64-channel MCG system, Hitachi Ltd., Japan) and MRs (Magnex 100, Shimadz, Japan). The location of pre-excitation was calculated using the Biot-Savart equation. The body model for the secondary currents was an infinite half-space one. Three-dimensional MRs were calculated from 2D MRs in the frontal and saggital planes. The magnetic source of pre-excitation was superimposed on 3D MRs, and compared with the successful ablation site.

3.2 Results

In 3D MRs, the aorta, all four chambers of the heart, endocardial and epicardial site of the venricular muscle were observed from any projection. Figure 2 is an example of magneto-anatomical map obtained from a patient with WPW syndrome (a 22-year-old male). The magnetic source in this patient was in the lateral site of the annulus of the tricuspid valve (red circle) and the distance between the magnetic source and the successful ablation site was about 10mm in the anterior-posterior view.

3.3 Conclusion

The location of accessory pathways was diagnosed through 3D magneto-anatomical mappings.

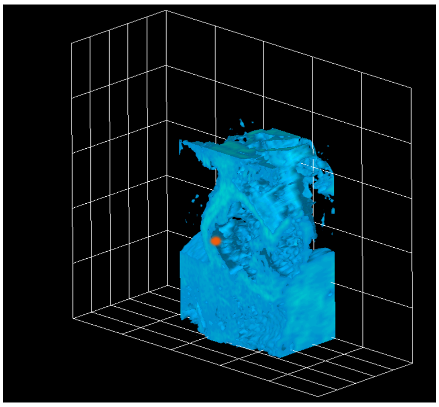
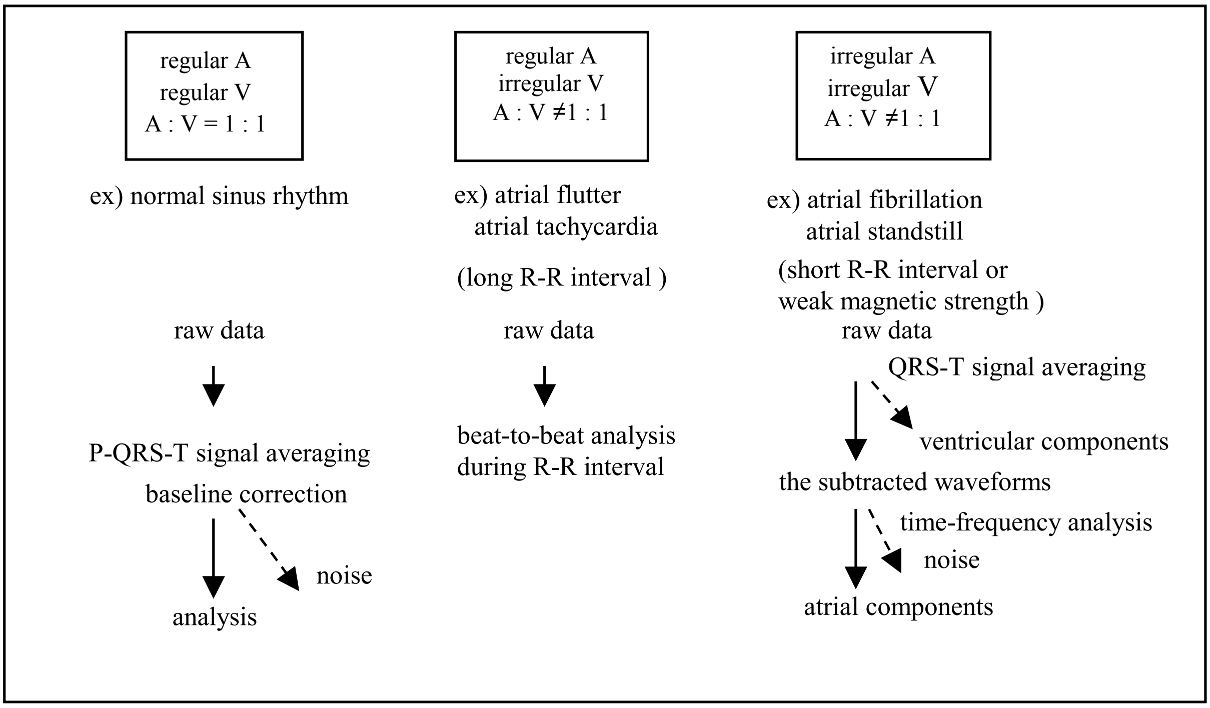


Figure 2: *A magneto-anatomical mapping in a patient with Wolff-Parkinson-White syndrome. This is a three-dimensional map in left anterior cranial view. The magnetic source of pre-excitation (red) is located at the 9 o'clock position along the tricuspid valve annulus.*

4 Discussion

In MCGs, the sampling data is usually signal averaged to reduce noise. Rapid atrial arrhythmias (AF, AT, and atrial fibrillation) are complex arrhythmias with short magnetically silent periods and irregular atrio-ventricular conduction. They are not amenable to P-QRS-T signal averaging. This is one of the reasons MCGs studies on atrial arrhythmias are rare in spite of the high morbidity associated with them (about 1% in the population more than 60 years old [11]). We made a new algorithm for analyzing atrial activation (Figure 3). In AF and AT (Section 2), atrial activation during a long R-R interval (slow atrio-ventricular conduction) was analyzed. Signal averaging and baseline correction are not done in this analysis. It shows details accompanied by beat-to-beat variability but also includes noises. In patients with diminished f waves, subtraction of QRS-T waveforms and time-frequency analysis manifest the existence of atrial activation. We succeeded in diagnosing partial atrial standstill noninvasively, even though EPS is conventionally needed for diagnosing this arrhythmia. Combined methods may be needed in the analysis of atrial fibrillation, because both mechanisms of micro-reentry and automaticity are included. Although the magnetic strength measured at the body surface is affected by the characteristics of the re-entrant circuit (size, figure, and the depth [12] etc.), this algorithm can be applied to ventricular arrhythmias.

Figure 3*: Algorithm for analyzing atrial tachyarrhythmias*



Abbreviations: A = atrial activation, V = ventricular activation, A:V = atrio-ventricular conduction ratio

The advantages of magneto-anatomical mappings are shown in table 1. A major one is that it provides anatomical information about the epicardial site. Epicardial information is important when diagnosing arrhythmias in patients with congenital heart disease, myocardial infarction with aneurysm, or a prior history of cardiac surgery. This system can be used to guide CA simulation and reduce the radiation time and frequency of complications in CA.

In conclusion, this study indicates that MCGs can be used to diagnose more complex arrhythmias.

Support

This work was supported by a Granted-in-Aid (No. 10357011) for Scientific Research from the Ministry of Education in Japan.

Acknowledgements

We thank Mr. M. Sasabuchi, Mr. H. Suzuki, Mr. K. Teshigawara, Mr. K. Muramaki in the Instrument Division of Hitachi Ltd., and Mr. K. Akamatsu in the Tsukuba Medical Center Hospital for their cooperation.

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Table 1: *Comparison between electrophygiologic study, electro-anatomical mappings (CARTO), and magneto-anatomical mappings*

	EPS	Electro-Anatomical Mappings (CARTO)	Magneto-Anatomical Mappings
Electrophysiological information			
Endocardial site	◎	◎	○
Epicardial site	△	△	○
Anatomical information			
Endocardial site	△	○	◎
Epicardial site	△	△	◎
Analysis	Beat-to-beat	Beat-by-beat	Beat-to-beat
Radiation	+	+	-
Treatment	Catheter ablation	Catheter ablation	-
Invasive / Noninvasive	Invasive	Invasive	Noninvasive

Abbreviation: EPS = electrophygiologic study

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